



Measuring Accurate Turbulence using Commercial Lidars

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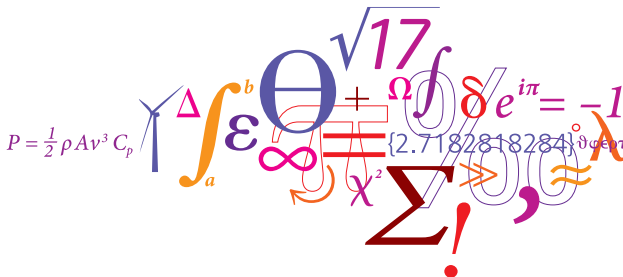
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Measuring Accurate Turbulence using Commercial Lidars

EWEA 2015, Paris

A. Sathe

DTU Wind Energy



Outline

- Motivation

Outline

- Motivation
- Measurements – Part 1

Outline

- Motivation
- Measurements – Part 1
- Measurements – Part 2

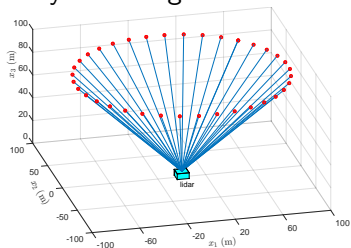
Outline

- Motivation
- Measurements – Part 1
- Measurements – Part 2
- Conclusions

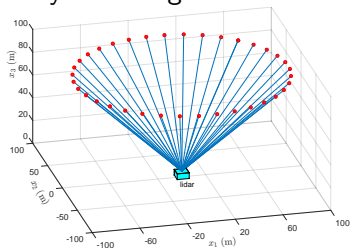
- How can the commercial lidars be used as stand-alone instruments for estimating turbulence statistics?
- Could we somehow achieve a slope close to one, e.g. $TI_{\text{lidar}} \approx TI_{\text{reference}}$?
- What extra measurements, if any, are required for that purpose?

Commercial Lidar Scanning Configurations

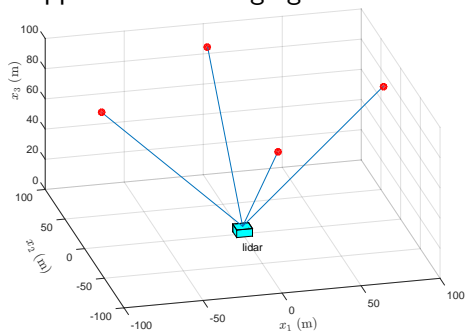
Conically Scanning



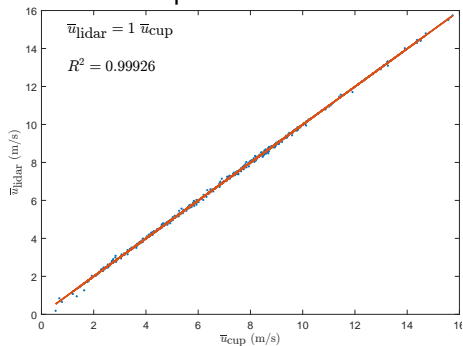
Conically Scanning



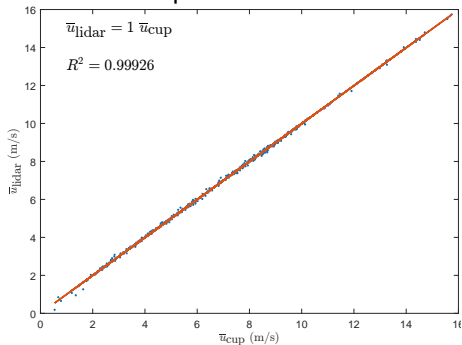
Doppler Beam Swinging



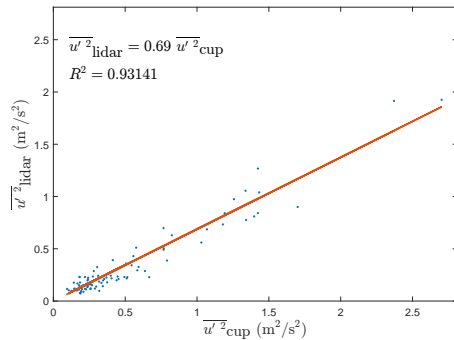
Mean Wind Speed



Mean Wind Speed

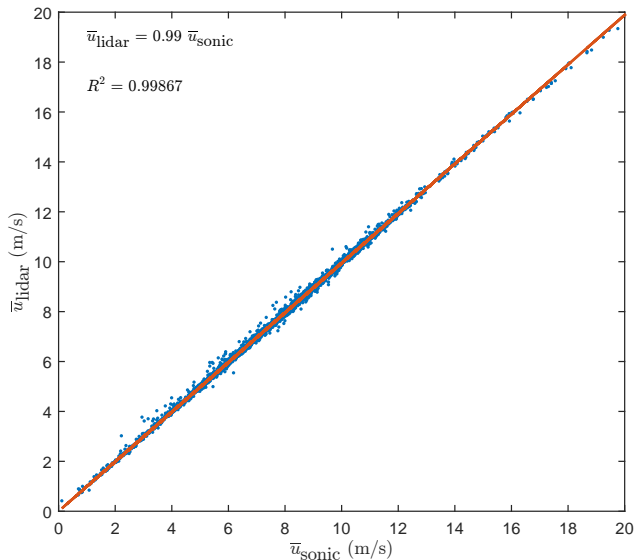


Turbulence



Comparison of the mean wind speed

Comparison of the mean wind speed

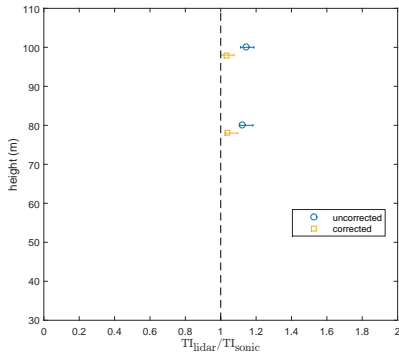


Improvement in Turbulence Intensity Estimates – Very Unstable



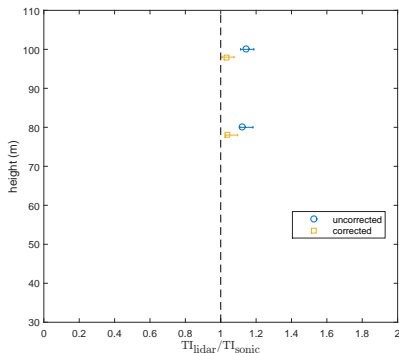
Improvement in Turbulence Intensity Estimates – Very Unstable

Ratio of TI_{lidar} to TI_{sonic}

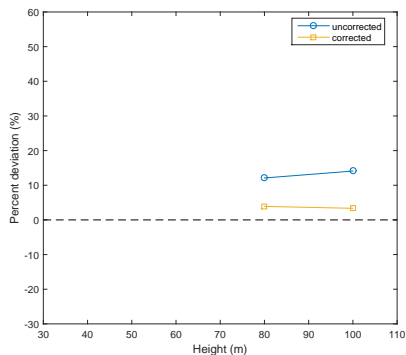


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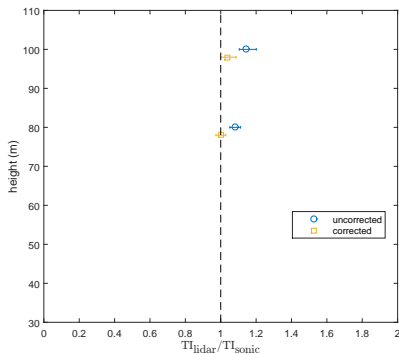
Ratio of TI_{lidar} to TI_{sonic}

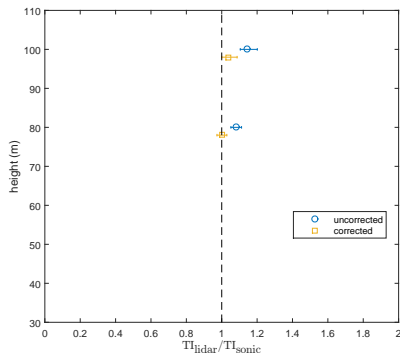
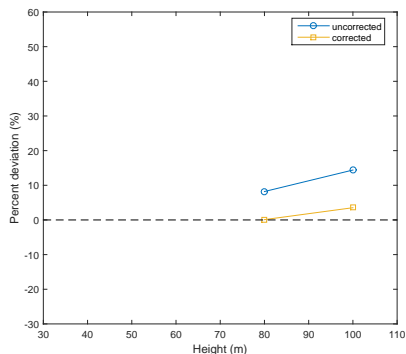


$(TI_{\text{lidar}} - TI_{\text{sonic}}) / TI_{\text{sonic}} \times 100$



Ratio of TI_{lidar} to TI_{sonic}

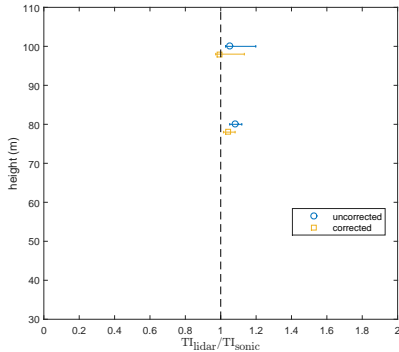


Ratio of TI_{lidar} to TI_{sonic}  $(TI_{\text{lidar}} - TI_{\text{sonic}})/TI_{\text{sonic}} \times 100$ 

Improvement in Turbulence Intensity Estimates – Near-Neutral Unstable

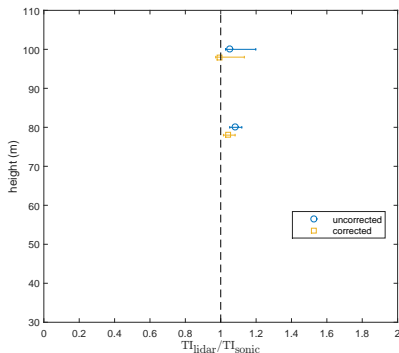
Improvement in Turbulence Intensity Estimates – Near-Neutral Unstable

Ratio of TI_{lidar} to TI_{sonic}

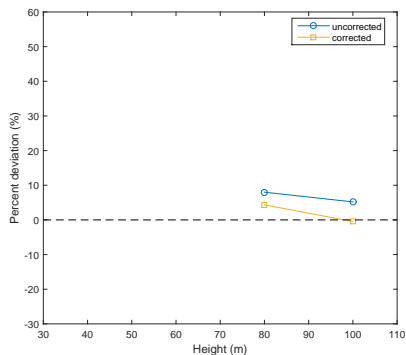


Improvement in Turbulence Intensity Estimates – Near-Neutral Unstable

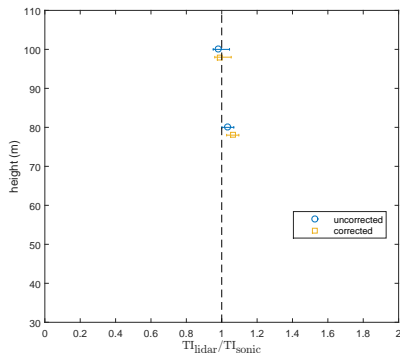
Ratio of TI_{lidar} to TI_{sonic}

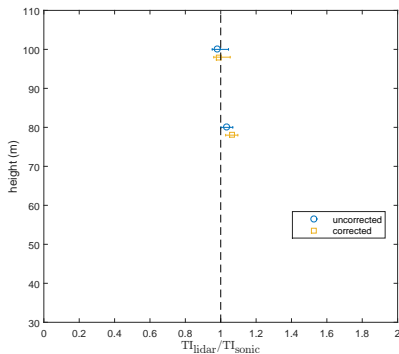
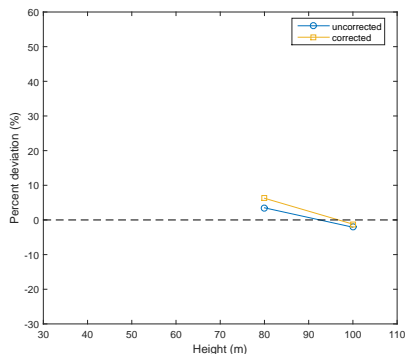


$(TI_{\text{lidar}} - TI_{\text{sonic}}) / TI_{\text{sonic}} \times 100$



Ratio of TI_{lidar} to TI_{sonic}



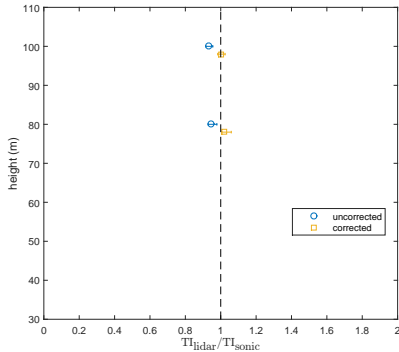
Ratio of TI_{lidar} to TI_{sonic}  $(TI_{\text{lidar}} - TI_{\text{sonic}})/TI_{\text{sonic}} \times 100$ 

Improvement in Turbulence Intensity Estimates – Near-Neutral Stable



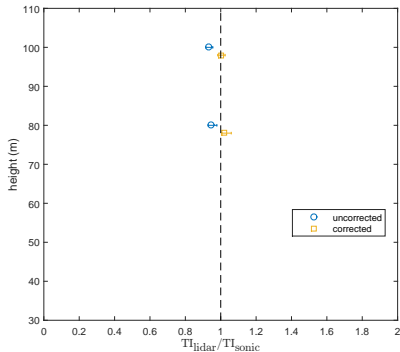
Improvement in Turbulence Intensity Estimates – Near-Neutral Stable

Ratio of TI_{lidar} to TI_{sonic}

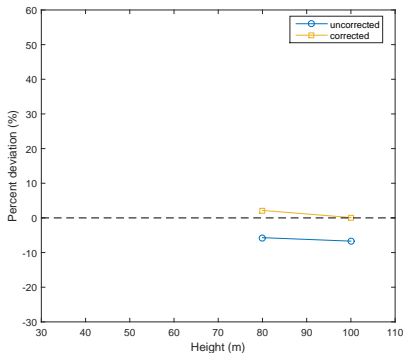


Improvement in Turbulence Intensity Estimates – Near-Neutral Stable

Ratio of TI_{lidar} to TI_{sonic}



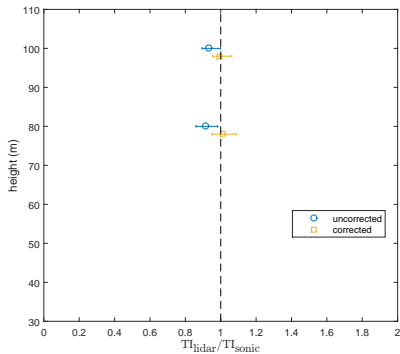
$(TI_{\text{lidar}} - TI_{\text{sonic}})/TI_{\text{sonic}} \times 100$

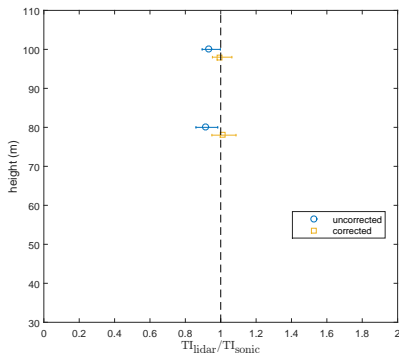
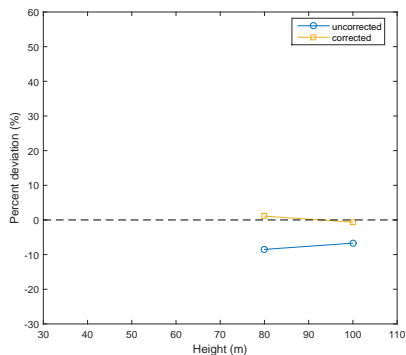


Improvement in Turbulence Intensity Estimates – Stable

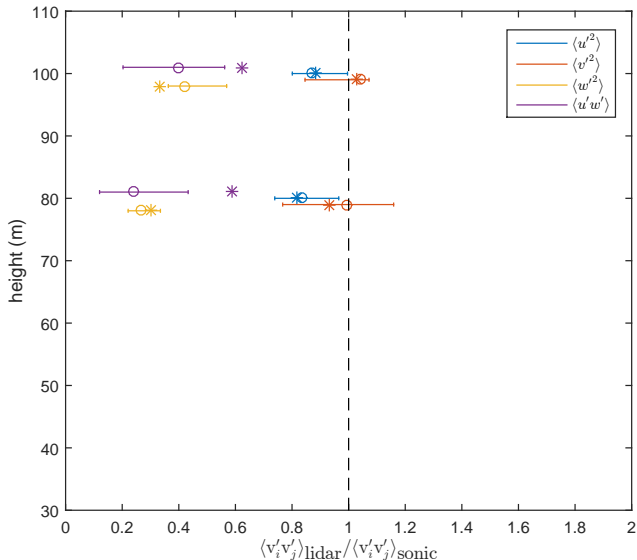


Ratio of TI_{lidar} to TI_{sonic}



Ratio of TI_{lidar} to TI_{sonic}  $(TI_{\text{lidar}} - TI_{\text{sonic}})/TI_{\text{sonic}} \times 100$ 

Comparison of the modelled and measured systematic errors



Measurements – Part 1

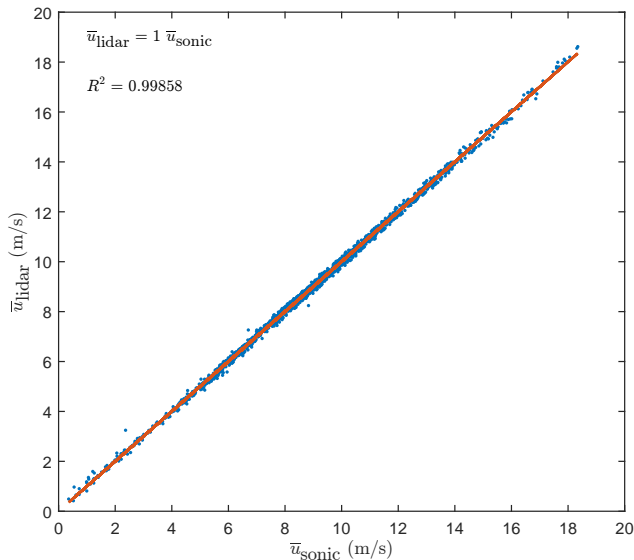
Summary of Part 1



Amongst all the cases the approximate percentage of cases when there is an improvement in TI measurements of WindCube using the SLEMT model at

- 80 m – 65 %
- 100 m – 81 %

Comparison of the mean wind speed

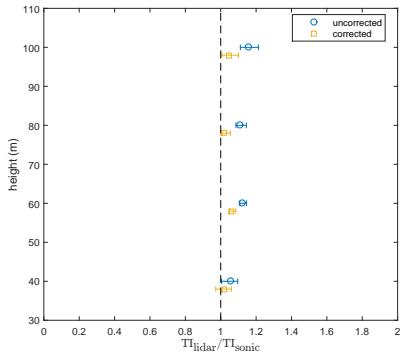


Improvement in Turbulence Intensity Estimates – Very Unstable



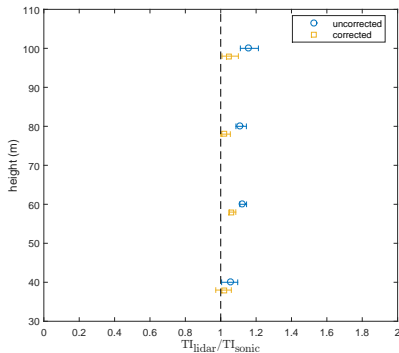
Improvement in Turbulence Intensity Estimates – Very Unstable

Ratio of TI_{lidar} to TI_{sonic}

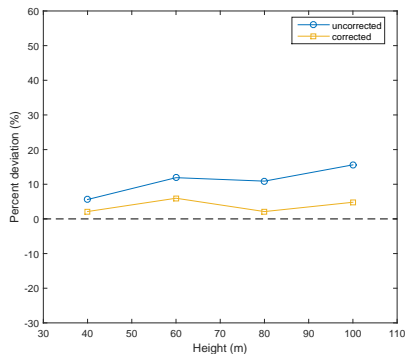


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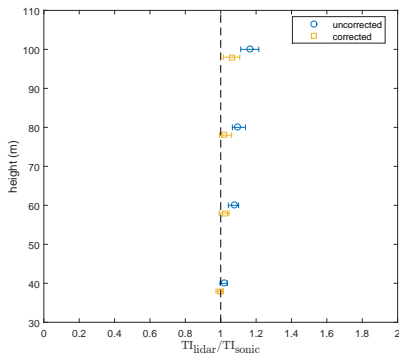
Ratio of TI_{lidar} to TI_{sonic}

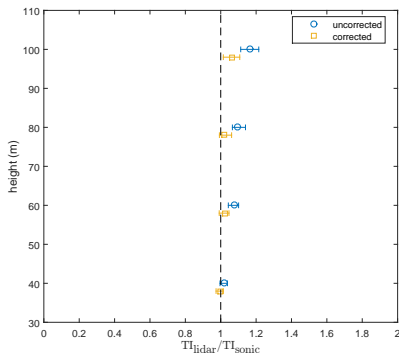
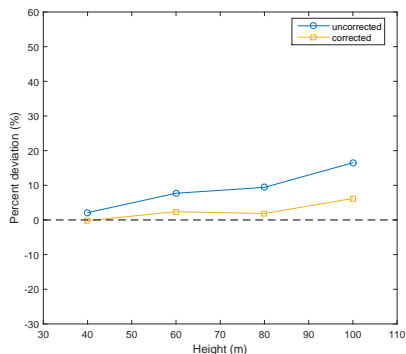


$(TI_{\text{lidar}} - TI_{\text{sonic}})/TI_{\text{sonic}} \times 100$



Ratio of TI_{lidar} to TI_{sonic}



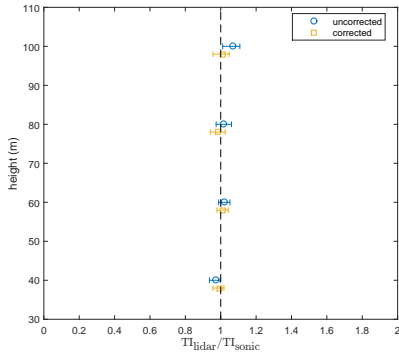
Ratio of TI_{lidar} to TI_{sonic}  $(TI_{\text{lidar}} - TI_{\text{sonic}})/TI_{\text{sonic}} \times 100$ 

Improvement in Turbulence Intensity Estimates – Near-Neutral Unstable



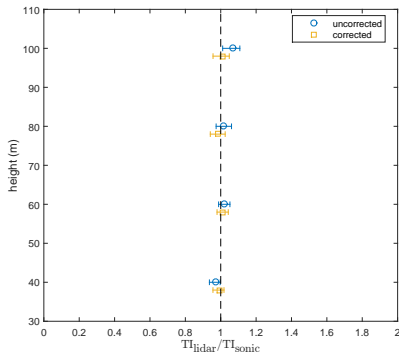
Improvement in Turbulence Intensity Estimates – Near-Neutral Unstable

Ratio of TI_{lidar} to TI_{sonic}

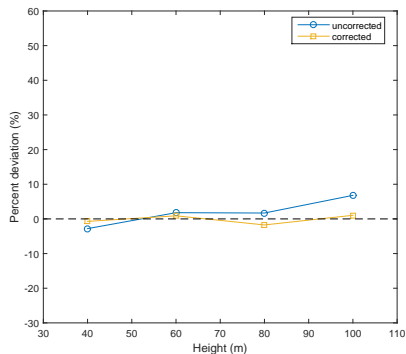


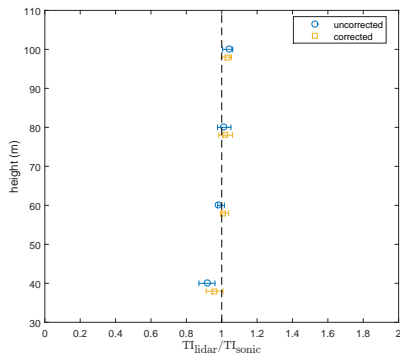
Improvement in Turbulence Intensity Estimates – Near-Neutral Unstable

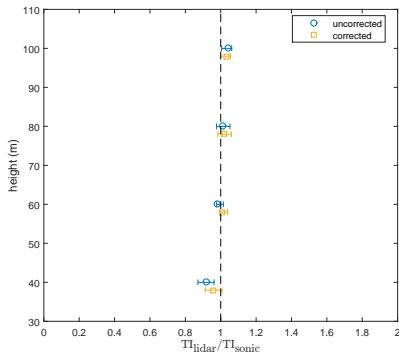
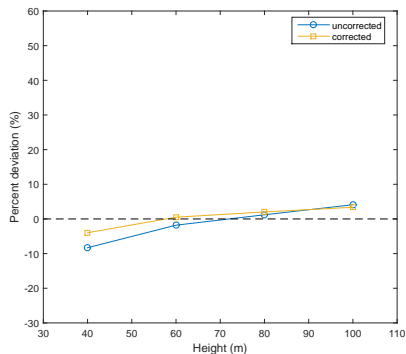
Ratio of TI_{lidar} to TI_{sonic}



$(TI_{\text{lidar}} - TI_{\text{sonic}}) / TI_{\text{sonic}} \times 100$



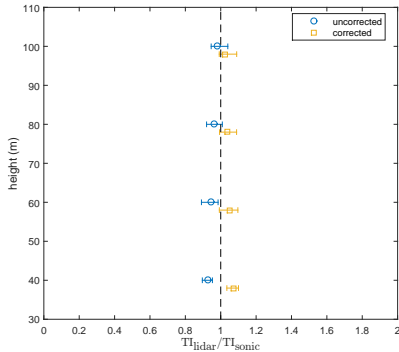
Ratio of TI_{lidar} to TI_{sonic} 

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Improvement in Turbulence Intensity Estimates – Near-Neutral Stable

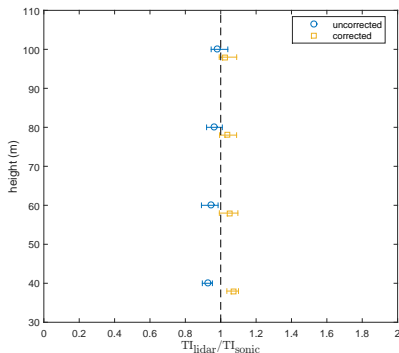
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Ratio of TI_{lidar} to TI_{sonic}

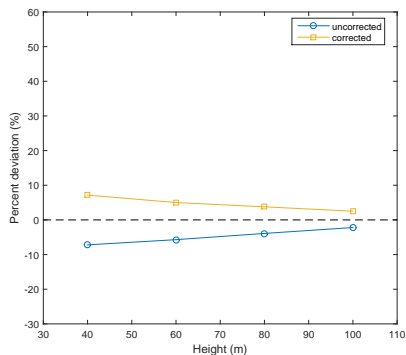


Improvement in Turbulence Intensity Estimates – Near-Neutral Stable

Ratio of TI_{lidar} to TI_{sonic}



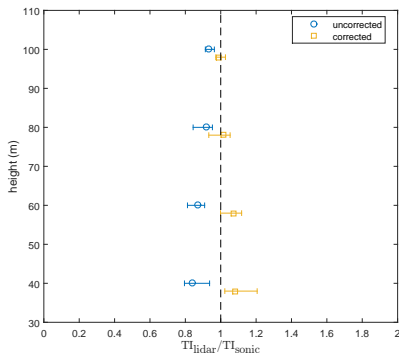
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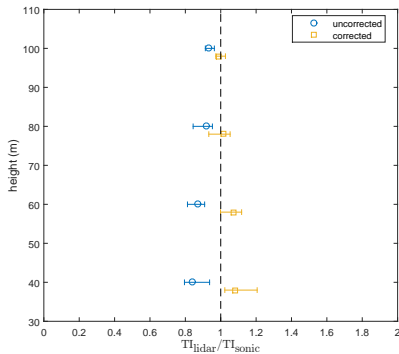
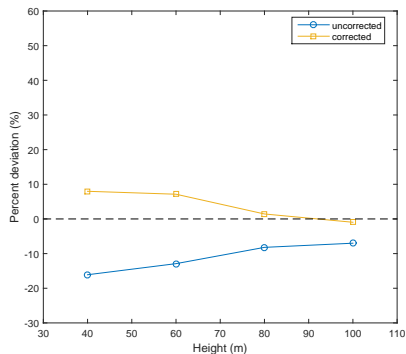


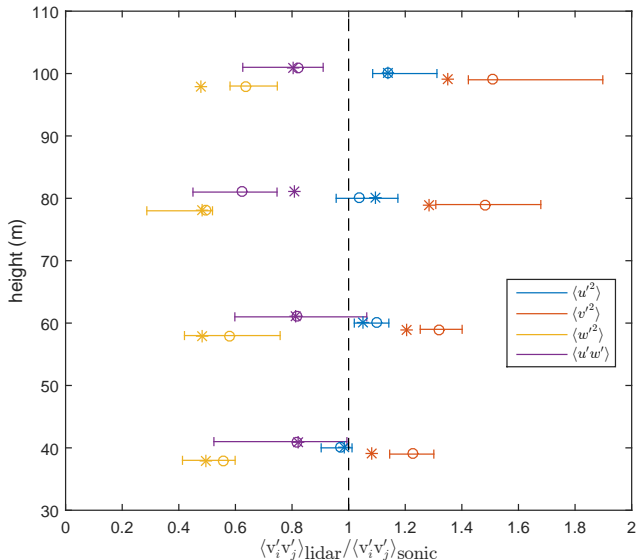
Improvement in Turbulence Intensity Estimates – Stable



Ratio of TI_{lidar} to TI_{sonic}



Ratio of TI_{lidar} to TI_{sonic}  $(TI_{\text{lidar}} - TI_{\text{sonic}}) / TI_{\text{sonic}} \times 100$ 



Measurements – Part 2

Summary of Part 2



Amongst all the cases the approximate percentage of cases when there is an improvement in TI measurements of WindCube using the SLEMT model at

- 40 m – 72 %
- 60 m – 52 %
- 80 m – 53 %
- 100 m – 70 %

Conclusions

Next Steps

Conclusions

- For majority cases, the DTU Wind Energy model improves TI estimates using the WindCube data even when the lidar measurement period does not overlap with those for which the correction factors were obtained
- The method shows potential of using WindCube as a stand-alone instrument for estimating turbulence, if atmospheric stability can be characterized using a sonic at a lower height or by any other method

Next Steps

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Next Steps

- Obtain data from one or two offshore locations where the WindCube is co-located with the mast
- Apply the estimated correction factors to the WindCube data from these locations

Key Learning Objectives - Revisited

How can the commercial lidars be used as stand-alone instruments for estimating turbulence statistics?

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By combining DTU Wind Energy model and lidar measurements

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Yes, but the limitation of the method is that the site must be horizontally homogeneous. It has a good potential offshore, where not a lot of measurements are available, and the conditions are approximately homogeneous.

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What extra measurements, if any, are required for that purpose?

Atmospheric Stability! The most desired solution would be to have a 10 m met mast with a sonic anemometer. However there are also other ways to estimate stability, e.g. using Richardson numbers.

Thank you!
amsat@dtu.dk